Gustav Theodor Fechner was a German experimental psychologist and philosopher. He is also considered by many to be the father of modern psychophysics. Initially, Fechner took a degree in medicine and worked in that area for a while. During that time he began publishing a series of humorous and satirical articles and poems lampooning the medical profession. These were published under the pseudonym Dr. Mises, and one of his most famous publications of this genre was on the *Comparative Anatomy of Angels* (1825). The writings of Dr. Mises certainly provide insight into the breadth and depth of Fechner’s intelligence and abilities.

Fechner then moved on to physics by learning about contemporary advances in electricity and magnetism through translation of great French works as well as handbooks of chemistry and physics into German. With this new knowledge in hand, Fechner taught at the University of Leipzig, eventually obtaining a professorship and making distinguished contributions to the field. Interestingly, Dr. Mises also continued to publish on occasion.

All along, Fechner was interested in the mind-body problem and desired to determine an empirical relationship between the physics of the world (and body) and the perceptions of the mind. Some of his studies in this vein included the discovery of perceived colors for slowly flickering black-and-white patterns (known as Fechner’s Colors or Fechner-Benham Colors after Benham made the work accessible in English) and the detailed study of color afterimages. It was the study of afterimages that set Fechner off in his next direction. He
was studying afterimages by staring at the sun through colored filters. This led him to give up his chair in physics in 1840 due to induced photophobia from eye injuries that made him an invalid, and overly sensitive to light, for about a decade.

During this period, on October 22, 1850, while lying in bed he finally figured out the basis of linking physical measurements in the environment with human perceptions in the mind that is currently referred to as Fechner’s law. Based on his knowledge of Weber’s law (coined by Fechner) that, for many perceptions, the ratio of a just-noticeable change in a stimulus to the initial magnitude of a stimulus is a constant, Fechner figured out that the differential equation implied by Fechner could be integrated and assumed that the just-noticeable differences could be summed to predict perceptual magnitude. The resulting relationship, now termed Fechner’s law, mathematically suggested that the magnitude of a perception would be proportional to the logarithm of the stimulus intensity.

More modern knowledge tells us that the specific relationship depends on the perceptual quantity and that it is not valid to sum JNDs to predict magnitudes. Nonetheless, Fechner’s contribution was very significant in founding the field of psychophysics. Fechner published further details of the theory and practice of psychophysics in his seminal work, Elements of Psychophysics (1860), [1] which remains a useful guide for practitioners in the field. Interestingly, Fechner is also credited with being the first to introduce the concept of the median to formal data analysis.

From Boring’s introduction in Adler’s translation of Elements of Psychophysics, we find that Fechner was for 7 years a physiologist (1817–1824), for 15 years a physicist (1824–1839), for 12 years an invalid (1839–1851), for 14 years a psychophysicist (1851–1865), for 11 years an experimental estheticist (1865–1876), and for periods throughout a philosopher.

References
is called usually either Behnam’s top or Behnam’s disk. Figure 1 shows some examples of a Behnam’s top. Variations in the disk include having thicker single lines or thinner three parallel lines.

To generate these illusory colors, it is important that the flicker rate of the stimulus is not too slow or too fast. The flicker is noticeable and the stimulus is well short of the critical fusion frequency. The rate of alternation of the black and white areas is not terribly fast with effective stimuli frequencies going from 3 Hz on up with optimal rotational frequencies for the spinning disk of about 4–6 Hz \([3, 4]\). The direction of the spinning seems to affect the colors experienced \([10]\).

**Creating and Measuring Fechner Colors**

To create Fechner colors, the disk is usually spun in the frequencies reported above. Colors are experienced in bands located where the black lines will be flickering \([5]\). While Behnam’s top represents a traditional means of creating the colors, researchers have developed many alternatives in trying to understand how these illusory colors occur \([4, 7, 9, 10]\). It is also not necessary that a spinning disk or top be used. A stationary flickering stimulus can be used \([7]\) though there is some evidence that the colors are not as easily seen \([9]\). To see an online example that uses a flickering stimulus, the reader is referred to Krantz \([8]\).

Measuring Behnam’s top has been approached several ways over the years. The most common methods use some form of color matching to determine the color experienced by the participant. Schramme \([10]\) used a color matching paradigm where a mirror was used to overlay the color patch onto the spinning disk. Then participants tried to match this patch to the illusory colors they were seeing. Rosenblum, Anderson, and Purple \([9]\) used Munsell color chips to make the color matches which served them well as they were interested if the illusory colors show some of the features of color matching errors seen in dichromats. Jarvis \([7]\) used a binocular matching method where the illusory colors were presented in one eye and the matching color was presented in another eye. In all of these methods, the attempt was to try to determine the color perceived by the observer.

Results from various studies over the years have revealed several interesting features of Fechner colors. First, the colors experienced are always desaturated, that is, somewhat washed out \([7]\). These colors can vary in their vibrancy in ways that depend upon the method of generation, but natural colors can much more easily be made to be highly saturated. Many reports indicate a wide range of individual differences in the colors experienced \([6]\). While most visual phenomena have some individual variation, there is a remarkable degree of agreement across observers. If there were not this agreement, then technologies such as color reproduction would not be feasible. This agreement is not seen in Fechner colors. Other researchers have observed that both illumination level and adaptation state alter the colors.
experienced, making the adaptation state of observers important to control in any experiment on Fechner colors [3, 4]. Perhaps one of the most interesting findings is that Fechner colors can be obtained with monochromatic, single-wavelength illumination as well as in full-spectrum neutral illumination [3].

Explanations and Future Directions

There have been many different types of explanations offered for the existence of Fechner colors in the almost 200 years since its discovery [1]. The challenge for any theoretical explanation is two-fold: how does a monochromatic or neutral color stimulation lead to the perception of colors and what is the role of the flickering rate? Another important factor to consider, often ignored in most theoretical attempts, is the individual differences in the colors reported by observers. Older explanations have involved fatigue in receptors, the role of complementary colors, and even factors related to Hering’s original theory of color perception. Most of these explanations have been ruled out by directly examining fatigue, contrast, and limitations of the complementarity of the colors experienced [1]. As more information about cone functioning developed, explanations developed that used ideas about differences in the speed with which different wavelengths of light are processed [3] and information about the relative speed with which the blue or short-wavelength cone responding to flickering stimuli compared to the speed of the other cones responding to the same flickering stimuli have been developed. The hypothesis is that it is the relative slowness of the short-wavelength cone in responding to flickering stimuli that is responsible for Fechner colors. The idea is that with slowly flickering stimuli, the short wavelength cone responds too slowly to pick up the flicker adequately, while the middle- and long-wavelength cones, red and green cones, respectively, still can respond. Thus, these cones do not adequately cancel each other out in the blue-yellow color opponent channel leading to the perception of colors. Shramme [10] found, using color matches, Fechner colors that fell along the blue-yellow axis of the 1931 CIE diagram that matched these expectations. Despite the sophistication and intuitive plausibility of this explanation, it is still safe to say that there is no generally accepted explanation for these illusory colors. Campenhausen et al. [4] propose a two-step model for Fechner colors that involves both summing of cone inputs in a noncolor opponent pathway and lateral interactions at the level of the horizontal cells. The support for this hypothesis comes from many lines of evidence but includes that Fechner color in areas that do not receive modulated light and that achromatic effects similar to Fechner colors can be produced in rod vision. Shramme [10], whose results seemed to support the possibility that Fechner colors were due to the slowness of the short-wavelength cone, proposed that Fechner colors actually arise in the blue-yellow ganglion cells. The argument here depended upon the ability to manipulate the perceived Fechner color along the blue-yellow axis of the CIE diagram in a manner which would have been hard to predict from the action of the short-wavelength cone alone. Using these two explanations as examples, it can be seen that even the level of the visual system involved is not agreed upon, though all theories do seem to argue that Fechner colors arise in the retina.

While these explanations are intriguing, future developments will be needed to combine, modify, or seek a new direction of explanation for Fechner colors. One feature of the findings that is rarely explained and needs to be is individual variation in the colors experienced. The actual mechanism of the temporal response needs to be further uncovered as this finding increases the evidence for multiple ways that the eye responds to temporally moving or flickering stimuli. It is possible that it is in the variations in temporal response that the individual differences of Fechner colors lie.
Finish, Textile

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Synonyms

Dry or mechanical finishing; Textile processing; Textile wet processing; Wet or chemical finishes

Definition

Textile finishing can be defined as all processes (chemical and/or mechanical), employed subsequent to textile coloration which impart additional functionality/superior aesthetics to the textile material. Mostly, textile finishing is applied to fabrics (woven, knitted, nonwovens); however, textile finishes can also be applied to fibers and yarns.

Introduction

The primary objectives of textile finishing are to improve the aesthetic and functional properties of textiles. In a broader sense, “finishing” relates to all processes that fabrics might be subjected to subsequent to weaving, knitting, or nonwoven manufacturing processes. The term “finishing” could include fabric preparation (e.g., singeing, desizing, scouring, bleaching, optical brightening process, mercerization process, etc.) and coloration (dyeing and printing); indeed, the combination of these processes is sometimes referred to as “wet-finishing” processes [1]. Another school of thought refers to “finishing” as the final stage of fabric preparation with the objective to prepare the fabric for the consumer and that the term “finishing” concerns only fabric treatment other than fabric preparation and coloration. In this chapter, finishing subsequent to coloration will

References

be discussed, in which context, it is important to check the compatibility of the finishing process with the treated substrate and the coloration process that has been previously implemented [2].

**Classification**

The conventional textile finishing methods can broadly be divided into two categories:

(i) “Dry” or “mechanical” finishes
(ii) “Wet” or “chemical” finishes

There are, however, finishing operations which combine mechanical and chemical finishes e.g., mercerization (the NaOH treatment of fabric on machines with or without tension).

**“Dry” or “Mechanical” Finishes**

The mechanical finishing of textiles may range from a simple drying operation to a complicated series of calendaring operations (Schreiner finisher). A few examples of the mechanical finishing of textile are discussed below.

**Drying**

It is well known that wet fabric can hold a large amount of water and that some of this held water can be easily removed by simple mechanical action. The efficiency of the process to mechanically remove the water from the fabric is vitally important from both cost and environmental points of view. High energy is required to evaporate the remaining water due to its high latent heat of evaporation. Machines such as mangles, centrifuges, and suction-slot machines are used in textile processing to remove water from fabric by mechanical means [3]. Drying machines are employed in textile processing with the purpose of removing the water that has not been removed by mechanical action. The majority of the dryers used in textile processing offer continuous throughput and a few examples of such machines are “hot flue”, “drum dryers”, “perforated drum dryers”, “tumble dryers”, etc. [1].

**Calendering**

In calendering, the fabric is passed between two heavy rollers. The rollers may vary in hardness, surface speed, and temperature. Fabric properties such as smoothness and luster can be improved using calendering [4]. Calender finishing can be of six types, namely, simple finishing or swizzling calendering, chasing calendering, friction calendering, Schreiner calendering, embossing calendering, and felt calendering. A few examples of calendering are discussed below.

**Friction Calendering**

The differential speed of the two rollers is carefully selected to produce effects such as “chintz.” The smooth metal roller normally rotates at a higher rate than the soft roller [1, 3]. Durable finishes (Everglaze) can be achieved using this method by adding a cross-linking agent [5].

**Embossed Effects**

In this technique, a fabric pattern is produced by calendering the fabric using an engraved heated metal roller and a soft roller [4]. To avoid slippage between the rollers, it is important to control the process accurately.

**Schreiner Finishing**

In “Schreinering,” fine lines engraved on a metal roller are transferred to the fabric. With appropriate fabric construction and by carefully engineering the line direction of the engraving, a soft lustrous handle can be achieved [3]. This treatment is used to give cotton fabric the appearance of silk [1]. Although the wash fastness of this effect is poor [1, 3], it increases the point-of-sale appeal [3].

**Napping**

Napping is a very effective way for imparting a soft handle to fabrics [6]. Fabrics of low-twist, staple fiber yarn can be used for napping [7]. The napping machine contains metal cards and the napping tool comprises rollers with curved metal wires [1] which pull the fiber ends to the surface of the fabric. One or both sides of the fabric can be napped [7].
Sanforizing
Fibers contain internal tensions as a result of the various manufacturing processes employed, and a pretreatment is required to nullify this effect, since, otherwise, there is a possibility of significant shrinkage of garments during washing. Sanforizing is a controlled mechanical shrinkage process without the use of any chemicals. This treatment should be the last treatment that is applied to the fabric [1].

“Wet” or “Chemical” Finishes
Although chemical finishing has always been an important process for textiles, the demand for high-performance textiles has grown exponentially in recent years and, as a result, so has the demand for chemical finishing [8]. The majority of chemical finishes for textiles are additive, where the finishing treatment results in an increase in substrate mass through sorption or deposition of chemical compounds. However, some chemical finishing can be subtractive, in which the treatment results in the fiber substrate losing mass as a result of chemical degradation. While chemical finishing is mainly applied to fabric, it can also be applied to loose fibers, yarns, garments, etc. Based on the life-span of the finish on the textile substrate, textile finishing can also be classified as transient and durable finishing. The most important aspect in this regard is the resistance of the finish to domestic washing [9].

Application of Chemical Finishes
While the application and formulation of chemical finishes depends on several factors, the most important factors are the composition of the material being treated and the chemistry of the functional chemical. Interaction of the finishing effects, compatibility of different chemicals, and the environmental/green credentials of the process are other factors to consider.

If the functional chemical finishes display high substantivity towards the substrate, then exhaust (immersion) application methods can be used and any of the textile dyeing machines employed for batchwise dyeing can be used for textile finishing. However, if the applied functional chemical has limited or low substantivity, then a continuous application method can be used. One such method is the pad-dry-cure method wherein the fabric is first immersed in a solution containing the functional chemical, followed by drying and finally “curing” to fix the finish within the fabric (Fig. 1).

Chemical finishes can also be applied to textiles using modern application techniques such as exposure of the textile substrate to plasma employing either low pressure, low-temperature plasma, or atmospheric plasma. Plasma, which is considered as the fourth aggregation state of matter, can be described as a mixture of partially ionized gases in which the constituents are achieved by external energy addition. The main advantage of such plasma treatments are:
- It consumes minimal chemicals compared to conventional finishing.
- No costly drying process is required.
- It is a surface treatment, so the bulk properties of the material are not affected.
- High environmental compatibility.

**Important Chemical Finishes**

A few commercially important chemical finishes are discussed below. Other types of chemical finishes include, but are not limited to, antistatic finishes, soil release finishes, insect resist finishes, flame-retardant finishes, stain resist finishes, non-slip finishes, UV-protection finishes, finishing to improve color fastness, etc.

**Softening Agents**

Softeners are one of the most widely used chemicals in textile processing, and as the name suggests, the application of softeners dramatically improves the handle and perceived quality of a fabric. In textile processing, one of the most important functions of softeners is to counteract the harshness imparted by other finishes (e.g., easy care). Softeners are, however, also used extensively in domestic washing formulations.

Although the main effects of the softeners are at the surface of fibers, the small molecules can impart internal plasticization of the fibers by reducing the glass transition temperature (Tg) of the fibrous polymer [8]. Early softeners were based on waxes and oils although modern types can be divided into five categories, namely, cationic softeners, nonionic softeners, anionic softeners, reactive softeners, and amphoteric softeners [3].

**Cationic softeners** are the most important type of softener for both industrial and domestic applications. The positively charged ends of the cationic softeners orient themselves towards the negatively charged fibers (zeta potential), creating a new surface of hydrophobic carbon chains that are responsible for the excellent softening effect of cationic softeners [8]. Because of the positive charge, these softeners are substantive towards cellulosic fibers, and exhaust application of these finishes is widespread using conventional textile dyeing machines (e.g., winch, jet, beam) [3]. Cationic softeners are known to exacerbate the soiling propensity of fibers and to inhibit soil removal. Dimethyldistearlammonium methosulfate is a good example of a popular cationic softener (Fig. 2). The use of silicone-based finishes in textile processing has grown steadily over the last 50 or so years [3]. Silicon-based cationic softeners provide a high degree of softness and a unique hand to fabrics. However, silicon softeners may contain variable amounts of siloxane oligomers, depending on the method of synthesis, which may be a cause of air pollution [8]. A popular range of silicon softeners are based on the weakly cationic amino functional siloxanes. Although these silicon compounds could potentially be applied from mild alkaline conditions, durability is improved by application at pH of 4.

**Nonionic softeners** are well known to perform multiple functions such as softeners, emulsifiers, stabilizers, extenders, and lubricants [3]. Paraffin waxes and similar materials are the most basic nonionic softeners. Molten polyethylene (Fig. 3) at high pressure can be air oxidized to secure hydrophilic characteristics (mainly carboxyl groups). High-quality, more stable products can be produced by emulsification in the presence of alkali. These products are stable to extreme pH conditions and can withstand the temperatures used for normal textile processing [8]. In recent years, polysiloxanes have gained importance as nonionic softeners (Fig. 4). Due to their limited substantivity, nonionic softeners, with very few
exceptions, are normally applied by non-exhaust methods (e.g., padding) [3].

Anionic softeners, due to the presence of the negative charge, are repelled from negatively charged fibers (e.g., cellulosic fibers) which leads to higher hydrophilicity [8]. These were among the first soft finishes to be used commercially and include long-chain alkyl sulfates, sulfonates, and succinates. Anionic softeners are used in specialized areas of application where the physiological activity is low, e.g., medical textiles. As the majority of fluorescent brightening agents are anionic, they are widely used in conjunction with anionic softeners for the resin finishing of white cellulosic fibers [3].

Reactive softeners contain functional groups capable of reacting with particular functional groups in some fibers [8] (e.g., the -OH group of cellulosic fibers). This type of finishing is permanent to washing due to the formation of covalent bonds between the softener and substrate. N-methylol derivatives of stearic acid amides and urea-substituted compounds are very successful as reactive softeners (Fig. 5) [3]. One example of a silicon-based reactive softener is given in Fig. 6, which is a modified siloxane and contains functional silanol groups. The silanol group could potentially be replaced by other functional groups such as amines or alcohols.

Amphoteric softeners have limited textile applications but are very popular in personal care products (e.g., shampoo formulations) due to their low toxicity [3]. One example of an amphoteric softener is shown in Fig. 7.

Water and Oil-Repellent Finishes
There is a distinction between “water-repellent” and “waterproof” fabrics. Waterproofing is achieved, for example, by coating the fabric with rubber. Such a treated fabric will not only be impermeable to water but also most notably against air and perspiration; as such, “waterproof” fabrics are uncomfortable to wear. A water-repellent finish, on the other hand, remains permeable to air and is achieved by the application of hydrophobic chemicals to the fabric [1]. These types of “water-repellent” finishes are normally used for clothing and will be discussed in this chapter. As very few textiles are inherently water repellent but none are oil repellent, so an additional process must be added to display these properties.

If the internal cohesive interactions within a liquid are lower than the adhesive interactions
operating between a solid surface and the liquid, then a drop of the liquid will spread on the solid surface. Based on this theory, repellent finishes (both oil and water) work on the principle of reducing the free energy of the fabric surface [8]. In this context, it should be mentioned that alongside the chemical composition of the material, the geometry of the textile surface also plays a significant role in the wettability of the textile [1]. It has long been recognized that superhydrophobic surfaces require a unique combination of two fundamental properties, namely, surface roughness and low surface energy [2]. The functional chemicals used to achieve water-repellent finishing significantly vary in their chemistry, their role being to reduce the surface energy of the fabric by adding lower surface energy chemical groups to the surface [3].

The chemicals traditionally used to achieve water repellence may be divided into a few groups: metal salts, soap/metal salts, wax, pyridinium-based finishes, organometallic complexes, N-methylol derivatives, silicone finishes, and fluorochemical finishes [3]. Among these, only fluorocarbon finishes are known to repel both oil and water [3, 12], whereas the other finishes can repel only water. Moreover, perfluorinated derivatives are effective at very low concentrations [1]. Polymeric fluorochemical finishes are typically acrylic or methacrylic polymers with perfluoro side chains. Silicon-based water repellents are also used (Fig. 8).

Easy-Care and Durable Press Finishes
As the name suggests, “easy care” and “durable press” are applied to textiles to impart minimum care properties, mostly to cellulosic fibers and their blends with other fibers. Various terms have been used to describe this area, including easy care, easy-to-iron, no iron, crease resistant, wrinkle resistant, wrinkle free etc. However the technically correct term is “cellulosic anti-swelling” or “cellulosic cross-linking” finishes [8].

Cellulose (natural or regenerated) is a linear polymer formed by the condensation of β-D-glucopyranose that contains 1→4-glycosidic linkages. The presence of hydroxyl groups along each chain creates extensive H-bonding both between (intermolecular) and within (intramolecular) the chains. Formation of such intramolecular H-bonds imparts “stiffness” to the cellulose molecules by restricting movement of the 1,4-β-D-glucopyranose units. The -OH groups are also responsible for the hydrophilicity of cellulosic fibers; owing to the high density of the -OH groups, cellulosic fabrics shrink in water and crease upon drying. The main function of easy-care/durable press finishing is to overcome shrinkage and wrinkling by cross-linking the -OH groups.

Although finishing agents are unable to penetrate the crystalline regions of the fiber, the easy-care/durable press finish needs to be of small Mₐ and preferably high reactivity to enable it to penetrate the amorphous region of the fibers [3].

It was demonstrated in the late 1920s that thermosetting resins (e.g., phenol-formaldehyde, urea-formaldehyde) could impart crease resistance to cellulosic fabrics. Since then, numerous publication and patents have described novel cross-linking reagents based on urea-HCHO chemistry [4]. This original type of easy-care products (urea-HCHO resins) used to contain high free formaldehyde, e.g., dimethylolurea (DMU) which is prepared from an excess of HCHO (Fig. 9). These nonreactant types of finishes are only durable to washing temperatures up to 60 °C. Wash fastness can be improved by using reactive resins such as methoxymethylmelamines (Fig. 10).
The first cyclic urea-reactant finishing agent was dimethylol ethylene urea (DMEU) which displays poor fastness to chlorine bleaching and adversely affects the light fastness of the finished fabric (Fig. 11). Cyclic urea-based finishing agents, \( N,N' \)-dimethylol-4,5-dihyroxyethylene urea (DMDHEU), comprise \( \sim 90\% \) of the easy-care/durable press finish products that are available in the market [8] (Fig. 12). Due to the presence of two hydroxyl groups at the C-4 and C-5 positions, the reactivity of DMDHEU is low, and therefore, reaction requires a catalyst. Although DMDHEU-containing products contain \( >0.3\% \) free formaldehyde, the search for formaldehyde-free finishing agents has spanned several decades [3] due to the toxicological effects associated with formaldehyde. Textiles containing a high level of formaldehyde can give rise to eczema and allergic reactions; furthermore, HCHO is a suspected human carcinogen [8]. Expensive formaldehyde-free finishing agents such as \( N,N' \)-dimethyl-4,5-dihydroxyethylene urea (DMeDHEU) (Fig. 13) is used for textile processing. DMeDHEU is less reactive than DMDHEU and therefore requires a stronger catalyst and harsher reaction conditions for successful cross-linking with cellulosic fibers.

**Antimicrobial Finishes**

Antimicrobial finishes are used to inhibit the growth of or to destroy microscopic organisms [3]. This could be for hygiene purposes, i.e. to protect the user from pathogenic or odor-causing microorganisms or to protect the textile material itself from damage caused by mold, mildew, or rot-producing microorganisms. Formaldehyde is a widely used biocide and preservation product. As discussed in the previous section, the majority of easy-care/durable press finishes contain HCHO, and therefore, these finishes display a small antimicrobial effect. However, for effective antimicrobial action, specific chemical finishes are used. Traditional antimicrobial agents such as copper naphthenate, copper-8-quinolinate, and numerous organomercury compounds are strictly...
regulated because of their toxicity and potential for environmental damage [8].

A common antimicrobial agent extensively used for cellulosic material is polyhexamethylene biguanide (PHMB) which has long been used in applications such as cosmetics and swimming pools. Along with conventional textile applications, PHMB can also be used in the production of medical textiles. PHMB is cationic and therefore displays excellent durability on cellulosic material [3]. Triclosan (Fig. 14) is another antimicrobial agent that is used extensively in mouthwashes, toothpastes, deodorants, and on textiles. This is nontoxic to humans and used as durable antimicrobial finish on polyester and polyamide fibers and their blends with cotton and wool. Heavy metals such as silver, copper, and mercury can provide antimicrobial effect in the form of the metal or metallic salt. Antimicrobial high-performance textile fibers (e.g., polyester, nylon, etc.) can be produced that include nanoparticles of heavy metals (e.g., silver). Chitosan is a natural biodegradable polymer which is nontoxic and shows microbial resistant.

Conclusions

As a result of increasing demands for superior quality and functionality in textiles, the sophistication of textile finishes and finishing operations has increased. New types of finishing are being developed to provide novel effects such as fragrance finishes, well-being finishes, bionic finishes, as well as finishing for smart textiles, medical textiles etc. Parallel to the search for novel finishes, existing finishes (and application techniques) are constantly being scrutinized to ensure that processing is as efficient as possible from technical, economical, and ecological perspectives. Textile finishing can be expected to remain a highly valuable tool which can significantly enhance the value of the finished textile product.

Cross-References

- Colorant, Textile
- Coloration, Textile
- Dye
- Dye, Functional

References

Fixture (American English)

▶ Luminaires

Flame Light Lamps

▶ Combustion Lamp

Focal Colors

▶ Unique Hues

Forecast

▶ Color Trends

Four-Dimensional Color Vision

▶ Tetrachromatic Vision

Functionality of Color

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Synonyms

Color effects to humans and the environment; Color roles; Color uses

Definition

The use, informative, and aesthetic impact of color on humans and the environment.

Color and Function

Human environment may be considered as a system, since man and environment elements are mutually determinant in any sense – an interrelation concerned with demand of man for his environment. The function of the built environment is based on social demand, necessity raised to a social level.

Within the system of man and elements of his environment, structural relations are defined and sustained by complex functions. This complex is composed of three types of functions: utility, aesthetic, and informative ones. Utility function is understood as the designation and purpose of environment elements. Aesthetic functions bring about properties of environment elements which enable one to experience utility functions. Informative functions involve properties of environment elements by which their functions, uses, and operation become understandable for man. These preliminaries underlie the present day approach to environment color design, considering the totality of utility, aesthetic, and informative functions as the system of demands.

▶ Environment color design has to serve the expression of the complex function of environment elements. Various functions of color-bearing environment elements are strictly interrelated and are prone to change into each other, a characteristic to be considered in the methodology of environment color design as a design process. It is necessary to develop design methods suitable for simultaneous and differentiated consideration and coordination of these components [1–3].

Color function components of environment color design as a design process can be deduced from the man to color relations. The man to color relation cannot be regarded in an abstract way. Colors are always associated to some object, phenomenon, or process, implicating into this relation their complex functions. In this respect, the theory
of environment color design has been concerned with the possibility to express function by the color of the environment element. It can be stated, for instance, that more saturated colors of the color space, with longer dominant wavelengths, act dynamically, hence suit to express functions involving dynamism. The less the saturation of these colors, the lower their dynamism. The greater the hue, saturation, or lightness differences between members of color complexes to express a function, the more dynamic is the function expressed by them. The intensity of the expression of function is more affected by the variation of lightness differences than by saturation differences. Again, it is found that a function is expressed not so much by a single color but by a complex of several colors. Accordingly, the expression of function by the environment elements contributes to harmony relations of colors bore by the element, and Coloroid color harmony relations may be combined with function expression indices [3, 4].

Disclosure of the rules of function expression cannot rely solely on visual information, since it is physiologically possible that stimuli perceived by one of the sensory organs should create perceptions normally transmitted by another sensory organ.

Utility Function of Colors
Environment is the space for human activities aimed at satisfying human demands. Since the beginnings of society, architecture has been expected to meet human demands. Analysis of and reckoning with functions necessarily took place in every period, even if functional demands have significantly changed and developed through the ages. The scientific analysis of functions and a conscious, integrated attention to all the requirements could not, however, develop earlier than in contemporary age, at a higher level of social development. This has led from early functionalism, the narrow interpretation of function, to an extended, wide-range functional approach, to the complex consideration of the integer system of relations inclusive of demands, requirements, and the color environment.

Of course, this functional approach itself is undergoing development, although in its germs it has been present in every stage of development throughout the history of architecture and, recently, in environment color design. Nowadays, however, it has become more conscious, unambiguous, and scientific, and it has risen to be an important factor of the up-to-date approach. The relationship between structure and function in architecture has been recognized, and this knowledge unavoidably affected environment color design. The ideas of environment color designers have to be directed by modern scientific thinking.

Activities in various areas of the built environment have become extremely differentiated. Functions have become so manifold that categorization is not only difficult but may lead to misunderstandings. Nevertheless, functions need to be categorized; otherwise the relations between functions and colors cannot be delineated, and the role of colors in the utility function of the environment cannot be studied.

According to the activities accommodated, the environment can be divided into working spaces, community spaces, living spaces, and traffic spaces.

To demonstrate the usable function of colors in different institutions, hospitals will be dealt with in the next paragraphs. Functions of hospital buildings are very special. For some people, a hospital provides accommodation for a shorter or longer but nevertheless limited time, while for others it is a working place. Therefore, the demands of both groups have to be respected not only concerning construction and equipment but also coloration. The more so since these demands are sometimes contradictory [2, 5, 6].

In most cases, the state of mind of a patient is a priori somewhat abnormal. The lonely, worried patient, so to say forcibly dragged from his habitual environment, is in need of being addressed and protectively accommodated by his new environment. On the other side, the work of the medical staff requires a great deal of concentration, and excessive color effects may distract their attention or even disturb his work. These anomalies have led to the absurd dispute among color dynamists
as to whom should priority be given in the hospital ward.

In a hospital, honoring of the utility functions can be done according to different aspects. Coloration should help orientation. Applying a certain color for doors of rooms with identical or similar functions may eliminate much uncertainty. Doors not for patients may be colored so as to convey this information. Proper color design may express connections between rooms. Any obtrusive color sensation has to be avoided in examination rooms and surgeries. In bathrooms, natural color effects of the sun, sand, and water have to be mimicked. The patient finds his picture in the mirror pale and sickly if it is being colored by near strong reflections from a green surface. A similar pale-colored impression arises when the patient observes his face neighbored by fiery orange or fiery red colors. But in rooms frequently contaminated by blood, green should be applied as complementary to red. Ward walls possibly need cheerful, warming, approaching, but not very saturated colors. Eventual chromotherapeutic effects have to be exploited. A febrile condition in itself yearns for a cool environment. In a condition of depression, a multicolored environment has to be preferred. In a labor ward or an intensive care unit, a positively reassuring coloration has to be applied.

Aesthetic Function of Colors
Just as any work of art, every element of the environment, and the environment itself, is an inseparable unity of content and form. Just as the human environment is a space for human functions, environment elements serve somehow the realization, accomplishment, and completion of human functions, and by all that they fulfill their own function. Thus, the human environment is up to its aesthetic function if it expresses its utility function in conformity with unity of content and form – where content is the utility function and form is the shape and color of the elements [1, 3, 5].

The essential condition of an aesthetic effect is unity between content and form, as so defined. Furthermore, the objects forming the content of the environment, or indeed the entire environment, are essentially functional. It follows that the integral expression of content can be realized by the harmonious functioning of all the components of the entire space. The practical-utility and spiritual-mental components of function are interdependent. The mental arises, and is inseparable, from practical. Now it is not realistic any longer to believe that the aesthetic form of an object or space should be possible without knowing its function. Neither is it believed that there exist universal aesthetic formulae applicable in every case nor that it is possible to force upon the environment any fine color harmony without knowledge of its function. In environment color design, it is also necessary to consider how much importance is attributed to its practical functions from the point of view of human life as a whole. That is to say, any work and activity has its emotional, mental, and spiritual attachments. Therefore each object, tool, or space claims some of these attachments, depending on its role, importance, and function in human life.

Form becomes a necessity in the course of a “function experience,” imprinting on consciousness a harmony sensation as inseparable unity between content and form. Of course, the sight of a color complex may give aesthetic pleasure, but when separated from the content and function of the space, this pleasure is rather superficial, as it does not offer a full space sensation.

To be able to create a form expressing the message of the built environment, the designer has to be acquainted with relationships between environment structures, the so-called composition relationships, such as that of material-function-form, conditions of space effects, or the role of space-time-motion in an environment.

Informative Function of Colors
Information functions of environment serve to interpret for man the functions, the ways of utilizing, and the operation of the environment and its elements. An important part of the informative functions of the environment is expressed by color information. Depending on the message, color information may be interpreted as logic information or as artistic or aesthetic information.

Logic and aesthetic information are carried by the same elements, but a different structure
belongs to every form of message. They can be characterized partly by their different visual systems, by the differentiation of their complexity and structure, and partly by the psychical differences of their messages. A message is transmitted by highlighting, contracting, and grouping some visual codes in the information-bearing surface or space, while disregarding others. A group of colors attracts attention when it excels by regularity and its structure is well recognizable. Recently, the analysis of these relations has been tackled with the methods of semiotics. Although these studies mostly concerned other than visual structures, the results can also be applied to color dynamics.

Logic information is conveyed by standard codes; they are practical and strictly mental and transmit knowledge. They prepare decisions of receivers and control their behavior and attitudes. Logic information is transmitted, e.g., by internationally agreed safety color signals. Locations of these colors in the CIE diagram are seen in Fig. 1. For instance, green means information, orange warning, red prohibition, and blue instruction. A special field of the built environment is traffic. Traffic signal colors are plotted in Fig. 2. Recently, colors indicating various technological processes have been standardized, as seen in Fig. 3. A special field of technology is the color signals of pipelines. Color signals for the fluid carried have been standardized, including different uses of the same fluid. For instance, there are different signal colors for drinking water, for utility hot water, condensing water, hot water for heating, soft water, neutralizing sewage, and other applications. In Fig. 4, pipeline colors are plotted in the given Coloroid sections [3, 4].

Color information of aesthetic content is mostly emotional. It expresses inward conditions and the wish to exert mental and emotional effects based on a common semantic knowledge. Because of their operative and recording functions, visual codes are not only carriers of the message, and social ideas of the color-designed space as a work of art, but may also display the attitude typical of the artistic subject and culture. It follows from all these that color dynamics creates complex color conditions and puts them into a colored world; thereby it has a manifold message, that is, it both expresses and molds human consciousness and emotions. In other words, environment color design is an artistic activity.
on a large scale, a piece of art existing in the built space, and as such, it has not only to cope with its specific iconic task but also to meet the special conditions of color dynamics.

Functionality of Color in Architecture

Color, as a component of a building’s image may result directly from the constructive process as is the case of vernacular buildings from the past and present applied as in the local tradition, or otherwise it may be decided at the end of the construction when a protective coating is required. Nowadays architects prepare complete designs, with finishes included, though this is not always the case with color specifications, often left for the final phase. In one way or another, the many functions of color may be used in favor of architectural façades and exposed structures.

Color can turn buildings into landmarks, spoil the panorama or contribute to the identity of a place. Architectural color design may be considered a matter for experts, but because building exteriors are part of the public realm, color is inevitably subject to acceptance or rejection from users: owners, pedestrians and drivers. Color is a primary perception and, as such, it affects human beings at physical and psychological levels. Architectural color works simultaneously from the behavioral the practical and for the specific interest of architecture.

Color Functionality from a Practical Point of View

The physical properties of color may be widely utilized in architecture. Deciding building colors goes hand in hand with technical aspects of the material, as each one has particular appearance characteristics and comes with a palette of color specific to the product. The outermost layer of the building should be designed to resist weather and environmental conditions, such as low and high temperatures, rain, wind, dust, and pollution. Durability and maintenance are considerations to have in mind when thinking of exterior colors finishes, as some conceal dust better than others. As regards paints finishes in certain cases the best solution is to apply a coat of economic paint in order to have a clean façade considering that dark and saturated tones discolor easily. Natural cladding materials in appropriate colors may also be practical for reducing maintenance of high-rise buildings.
Color as part of visual ergonomics is given great importance in interior design, considering the time spent indoors. For the areas implicated, the colors of building exteriors are also relevant from the point of view of visual comfort. Color is used to compensate the glare effect, produced when high levels of luminosity from white or light-colored surfaces reflect back in the eye, causing discomfort and stress.

The climatic and natural lighting conditions of each location should be analyzed before taking color decisions, especially when critical situations occur, as in high latitudes during winter, when bright colors are preferred for visual aid, as opposed to dark nuances.

Design for energy conservation is a present trend in architecture. In order to ensure thermal comfort, sophisticated finishes are as important as design principles of insulation, orientation, ventilation, and color. In hot climates light colors and reflective materials serve to avoid overheating of roofs, while black surfaces, preferably opaque, are used in building exteriors for absorbing the maximum heat.

Color Functionality from a Behavioral Point of View

Color applied to building exteriors has the potential to benefit the user, improving and facilitating interaction with the surroundings. Color serves as an informative tool. It acts as a reference for content, identity, and location, but in order to accomplish its functions, it should be applied carefully, for color randomness and excess work in the opposite direction.

Color codification for safety, as used in industrial building, may be applied to architectural design in a conventional manner, for marking emergency exits and secure zones, or applied in a versatile way to building parts and elements for orientation. On border scale, Familiarization with large structures as fairs, residential blocks and commercial centers, may be successfully achieved by color design.

The semiotic function of color applied to architecture contributes to clarity. This color function is particularly helpful to drivers, as distinctive tones and combinations can be perceived from a distance. When approaching a market or a day-care center, an ordinary person could anticipate its role by the external colors, when these are in accordance with the use of the building.

The functions of color extend to the symbolic aspect as hues convey meaning. For example, a red door on a black wall would something about the owner’s personality, maybe an artist. Semiotics in a more strict sense applies to nationality and affiliation, as in Olympic colors. Similarly, corporate identity requires color in precise nuances and combinations. The colors of an oil company or a bank may be transferred to the façades of a building exterior. However, the preservation of the architectural character is in the hands of the designer.

Building exteriors acts as a backdrop to human activities, especially in cities. By maintaining a balance between excitement and relaxation in urban color schemes, monotony may be avoided, and outdoor spaces, enhanced. The aesthetic aspect of architecture is relevant to develop positive attitudes and a sense of belonging in the user.

Color Functionality from an Architectural Perspective

Architectural color is based on the formal characteristics of the building, such as composition style, material and proportions. Historical data and usage are also part of the information to be considered in the design. The setting, natural or man-made, is of great influence in the perception of the external appearance of buildings. Ideally, color design should meet the requirements of each project in the formal, semantic and contextual aspects.

Color serves for the optimizes building design by reinforcing style and concept. For functional and aesthetic purposes new constructions deserve a mindful color proposal.

Revaluation of existing buildings may be achieved through color design. An ordinary construction may be transformed by color, emphasizing its character, neutralizing its obtrusive effect or making unsightly parts less conspicuous. Buildings could recover their authentic character by color restoration. Proposals may be based on traditional color palettes, specific for the
location and architectural period. As an alternative to date nuances that approximate to the original ones could be applied according to the architectural style.

Facade **decoration** may be used to complement building fronts. This mode of coloring plays a key role in balancing architectural compositions to make them more pleasant on behalf of the human scale.

**Art and design** in the form of pictures, supergraphics, and *trompe l’oeil* paintings may be used in the renovation of unsightly elevations. These serve to visually integrate or decompose façades, giving value to blind walls and revitalizing of outdoor spaces.

On a greater scale color has the potential to **regulate the impact** of obtrusive structures within a context, in urban and natural settings.

### A Major Consideration in Architectural Color: Scale of Perception

Building finishes and colors have various functions according to the impact produced at different scales or distances of perception. This refers to the position from user to object, in this case a building. The relevant scales for architectural color perception are the architectural scale, which considers the building as a three-dimensional object; the detail scale, which focuses on its parts and language elements; and the context scale, which considers the setting, natural or man-made.

On the architectural scale color affects the perception of a building as it would in the case of a sculpture, having a direct influence on the **definition** of volume, plane, and proportions and, consequently, in the **articulation of three-dimensional form**. Ideally, at this scale, the object and its coloration produce an integral result.

On the detail scale color is important for achieving **order and balance** within a façade or architectural composition. The different parts of the building present an opportunity for sophisticated color design. Depending on the characteristics of the architecture, it may go from structure and volume to doors and moldings, and the respective materials, textures and shadows.

On the context scale the color of a building determines the degree of visual **attachment or detachment to the surroundings**. Building-context integration depends on multiple conditions apart from color: orientation, position, size composition, and material quality, amongst others. With ingenuity, color may work to make a building inconspicuous or even camouflage. On the other hand, it is easier to make a building standout by the use of bright or unusual colors. By following a color master plan, a building acts as part of a broader context, from street and block to town and region.

Building color is a changing component its equilibrium is fragile, and a subtle variation may easily modify the whole. Color is a design tool, but it may act as double-edged sword, as its potential may be reversed to cause discomfort, disorientation and **COLOR POLLUTION**. In the best interest of the user, architectural color should be handled in a knowledgeable way.

### Color Tectonics in Architecture

Tectonics in architecture and urban design is the discipline dealing with the principles of design, structure, construction, and ornamentation. Color tectonics refers to the function that color plays in accentuating these principles.

Color and form are codependent in built form. In architecture color plays many roles throughout the design process. Color is used dynamically in diagrams in the conceptual phase. In the design development phase, color can enhance the perception of physical form and define interior space. In detailing color can express the parts of the building that contribute to the whole. These color and form strategies will be present as material color in the finished building. In the architecture, color can be functional as an enhancement to form or abstract as expressive media. Color can be associative by carrying cultural values and meaning, as well as eliciting emotional response. In all cases color combined with form becomes another layer of interpretation and clarification of the intentions of the designer [7].

### Conceptual Phase

A building, like a city, has an order based upon a clear hierarchical relationship of parts to the
whole. Architecture begins with a concept expressed both verbally and in diagram. In the conceptual phase of the design process, line drawings are used to represent an abstract relationship of the essential parts of the building. These parts can be described metaphorically or formally, and the relationship of these parts to one another creates the generative idea that is the point of departure for the design. These relationships are often expressed as a dialogue between oppositions such as public/private or active/passive. They can also represent events in the experience of architecture such as hierarchy, separation, connection, transition, and assimilation. The drawings are usually monochromatic, but if one assigns colors to these diagrams representing the character of the part (i.e., red represents active functions and blue passive, or saturated hues might be dominant and muted hues subordinate), then color juxtaposition and contrasts can set up a more visually dynamic relationship of these parts in the diagram. These color choices in the conceptual phase are chosen for their dynamic relationships in juxtaposition rather than by functional criteria, but these colors will often influence choices in the design development phase such as the delineation of three-dimensional form, building materials, and lighting.

A repertory theater is a place where actors must project their voice to the audience without acoustical support. A design concept for a repertory theater by Louis Kahn was first expressed metaphorically as “a violin within a violin case.” The diagram was a box representing the outer shell of the building or the “violin case” with an irregular form inside representing the “violin,” an acoustically designed theater. In black and white, this is just a simple diagram. With color, however, the violin and violin case form an expressive dialogue between these parts, making them more dynamic and meaningful (Fig. 5).

**Design Development**

In the design development phase of a design process, color is used to accentuate or diminish three-dimensional form. The exploration of perceptual effects created by color, particularly the spatial effect of color, color and atmosphere, and the familiarity with the principles of camouflage [8] are helpful tools in this pursuit (Fig. 6). The color decisions here are based on how the eye perceives color and form. The accentuating and disguising of form with color are the techniques supporting color tectonics. Using color in models in this phase establishes color juxtapositions and contrasts that will be present in the final building. Model studies similar to the experiments by Lois Swirnoff [9] are valuable exercises.

The purpose of color tectonics is to use color to clarify and enhance the perception of building form. This form is made up of parts arranged hierarchically that unite to shape the whole. This color/form carries the aesthetic and expressive intentions of the architect, and clarity of expression is usually the goal. In some instances, however, there is an intention to disguise and actually
deconstruct the true form, and color becomes a powerful tool in this endeavor. This was the case in the Portland Building during the period known as deconstruction in architecture (Fig. 7).

**Detail**
The details of buildings carry expressive content. Structural details communicate what elements in the building are supporting and load bearing and what are non-load bearing and serve to enclose the building and define space within it. Many functional parts of a building are repetitive, and through this repetition patterns and rhythms are established which support the unity of the building as a whole. ▶ **Color contrasts** provide a powerful tool for making these parts visible in a meaningful way. In the main entry facade to the Fort Wayne Repertory Theater, light gray concrete is contrasted with darker brick to both characterize the structural forces within a large wall and to accentuate the main entry (Fig. 8).
Color Imagery

In the final or building phase of the design process, color choices are more specific. To this point color has been an integral tool in clarifying the conceptual and design intentions of the architect and not as a secondary consideration in the design process. The final color/form imagery will both convey these intentions and also carry meaning through cultural associations, symbolism, and emotional response. The use of colors from the natural and built environmental contexts can give the architecture a sense of place as well [10]. In this process color is a principal consideration through all phases. The imagery experienced in the architecture will carry these design ideas in form and structure through perceptual color effects, but there will be an additional layer of meaning with the associative uses of color and the aesthetic imagery from experiencing the architecture as a whole in its environmental context.

Cross-References

- CIE Chromaticity Diagrams, CIE Purity, CIE Dominant Wavelength
- Color Appearance
- Color Dynamics
- Color Harmony
- Color Palette
- Color Pollution
- Environmental Color Design
- Unique Hues

References


Fundamental Colors

- Primary Colors